

## ADP STUDY OF THE STRUCTURE OF IUE HALO

PI: Derck Massa  
Applied Research Corporation  
8201 Corporate Drive  
Landover, MD 20785

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We have extended the work of Savage and Massa (1987) on a sample of halo stars which are mainly at Galactic latitudes less than  $30^\circ$  and are very distant. This set of stars is ideal for studying the global properties of the halo for three reasons. 1) the long path lengths allow the detection of less abundant ionic species such as N V, 2) the low latitudes suppress the effects of peculiar vertical motions known to exist in the halo (Danly 1989) and, 3) the long path lengths tend to smooth out the clumpiness of the gas, allowing us to concentrate on global gas properties.

Savage and Massa (1987) demonstrated quite clearly that the effects of Galactic rotation influence the UV line data. Figure 1 is from Savage and Massa and shows the average interstellar absorption line velocity,  $\langle v \rangle = (v_- + v_+)/2$ , for the weak Si II line at 1808Å and the C IV 1550Å doublet. Here,  $v_-$  and  $v_+$  are the LSR velocity of the interstellar absorption at half absorption intensity on the negative and positive velocity part of the line profile. The average velocities for Si II and C IV are plotted against  $v_r(d)$  which is the expected LSR radial velocity of absorption at the distance of the various stars with the assumption that disk gas and halo gas corotate. The points in Figure 1 are separated according to whether or not the star is located near the disk ( $|z| < 0.5$  kpc, solid circles) or in the halo ( $|z| > 0.5$  kpc, open circles). If interstellar absorption arises from an optically thick slab of gas with a large scale height which is corotating with the Galactic disk, then the mean absorption would always be  $v_r(d)/2$ , indicated by line of slope 1/2 in the figure. Note that the Si II data for the disk stars follow the line, demonstrating the effects of galactic rotation, while the halo stars do not. This behavior is most easily interpreted in terms of a small scale height for the Si II. Thus, once  $|z|$  exceeds  $\sim 0.5$  kpc, there is very little Si II and the line of sight simply runs out of absorbing gas. In contrast, the data for C IV for the disk and halo stars both follow the line to larger  $|v_r(d)|$ . Since C IV has a larger scale height than Si II, the effects of galactic rotation are even apparent in the data for the halo stars. Comparison of these two plots clearly demonstrates how Galactic rotation and the density distribution of a particular ion are intimately linked. Notice too, that in those cases where  $|v_r(d)| > 100$  km/s it appears that even the C IV data do not follow the average velocity expected if corotation were occurring. The C IV data of Figure 1 suggest that the assumption of corotation may become invalid at the larger  $|z|$  distances.

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During the period covered by this project, we extended the simple global analysis outlined above, and performed a detailed analysis of the density and kinematics of halo gas along two kinematically interesting lines of sight. This resulted in 2 publications (Savage, Massa and Sembach 1990, Sembach, Savage and Massa 1991). The basis of these analyses was high quality IUE absorption profiles obtained by adding several spectra taken at different locations in the IUE large aperture to reduce the effects of fixed pattern noise. The interstellar absorption profiles were converted into " $\tau$  plots". These are derived by taking the log of the residual intensity of the line profile and they can be compared directly to the predictions of a model for the kinematic and density structure of the absorbing gas along the line of sight.

This technique and the models used to analyze the data, were developed under this grant (details are given in the papers cited above). Figures 2a and b show how changing the parameters in the model affect the calculated profile for the line of sight toward HD 156359. The profiles are clearly very sensitive to the model parameters. Figure 2c and compare the Si IV and C IV profiles in HD 156359 to the models.

Because only two lines of sight have been analyzed in detail, it is premature to make strong conclusions concerning the global nature of the halo gas. In order to extend our effort to more complex models and to incorporate more lines of sight, it is no longer possible to represent all of the data on a single graph. Therefore, if one wishes to test more complicated models, different criteria must be adopted, such as a measure of a  $\chi^2$  statistic. Currently, the comparison between the model and observed parameters is weighted by a combination of the expected measurement AND DISTANCE uncertainties. The latter effect can be quit large for certain lines of sight. We treat each line from a given ion separately, since each represents an independent set of observations. For example, if both components of the C IV 1550 doublet can be measured, this gives us two independent measurements for the line of sight. The program uses the amoeba simplex algorithm to minimize the squares of the weighted differences between the observed and model quantities.

Clearly, there is a wealth of parameters which can be chosen as variables, so we have begun with a very simple case. Figure 3a shows the observed equivalent widths of C IV 1548, 1550 (about two thirds of the sample had measurements for both components) versus those of a model in which the mid-plane density and scale height were optimized (corotation was assumed, and we adopted an RMS velocity dispersion of 26 km/s for the gas, in accordance with Jenkins 1978 results). Figure 3b shows similar results for a static model, in which a constant velocity dispersion of 26 km/s was used. The effects of Galactic rotation on the fits is clearly apparent. The RMS dispersion for the two models are 0.21 and 0.29 dex for the dynamic and static models respectively. The former is close to the expected measurement error, ~50% or 0.18 dex, while the latter represents an error nearly twice this large.

The parameters derived from the optimization scheme differ significantly from those derived by Savage and Massa (1987) from essentially the same sample of stars. The Savage and Massa mid-plane density and scale height were  $7.0\text{E-}9 \text{ cm}^{-3}$  and 3.0 kpc, while the optimization scheme gives  $1.02\text{E-}8$  and 5.62 for these same quantities. It is interesting that both are larger, and that they combine to produce a vertical column density of  $1.8\text{E}14 \text{ cm}^{-2}$  as opposed to  $6.5\text{E}13$  -- more than a 60% difference.

Figure 4 shows a plot of the observed half intensity velocities versus those from the dynamic model. There is clearly unaccounted for structure present in the data and, hence, additional information can be extracted. Whether this can be accounted for by employing different density structures, such as a "transition region" near  $|z| = 1$  kpc, or if it is necessary to invoke kinematical influences remains to be seen, and improvements upon the preceding analysis are currently being pursued under a new ADP grant.

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Sembach, K., Savage, B.D. and Massa, D. 1991, ApJ, 372, 81

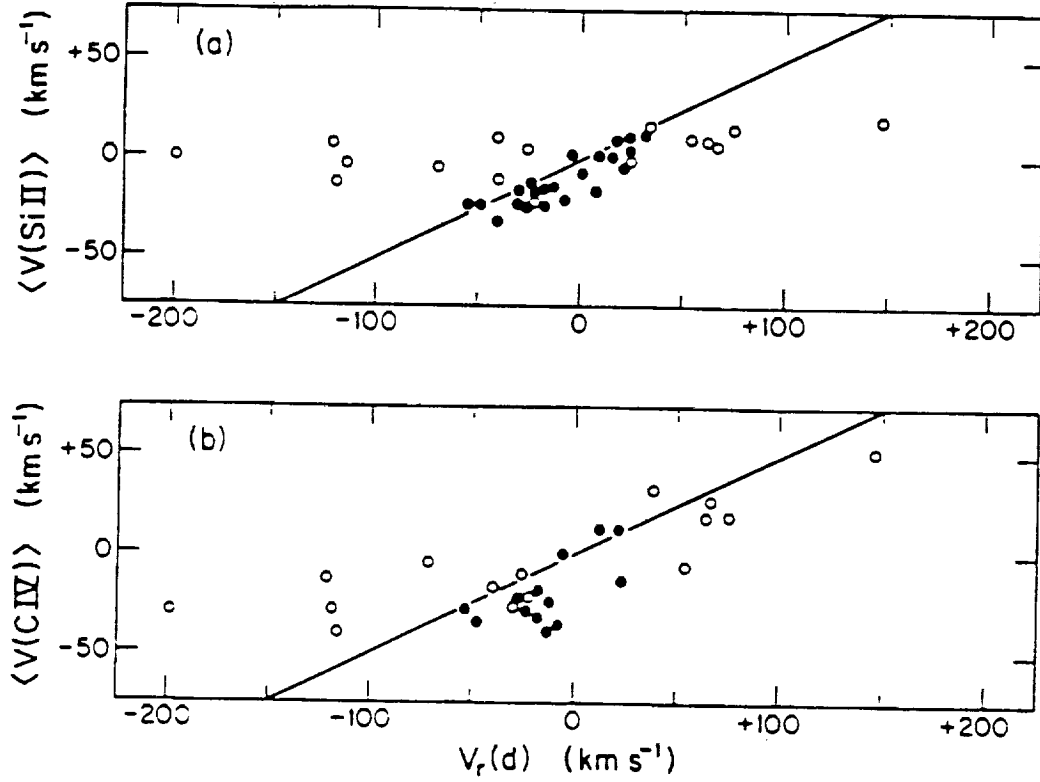


Figure 1. The average LSR interstellar absorption velocities of Si II  $\lambda 1808$  (Fig. 1a) and the mean of the C IV  $\lambda 1550$  doublet (Fig. 1b) versus the expected LSR radial velocities for each star in the Savage and Massa (1987) sample. The line has a slope of 1/2. Filled symbols are for stars with  $|z| < 0.5$  kpc, and open symbols are for stars with  $|z| > 0.5$  kpc.

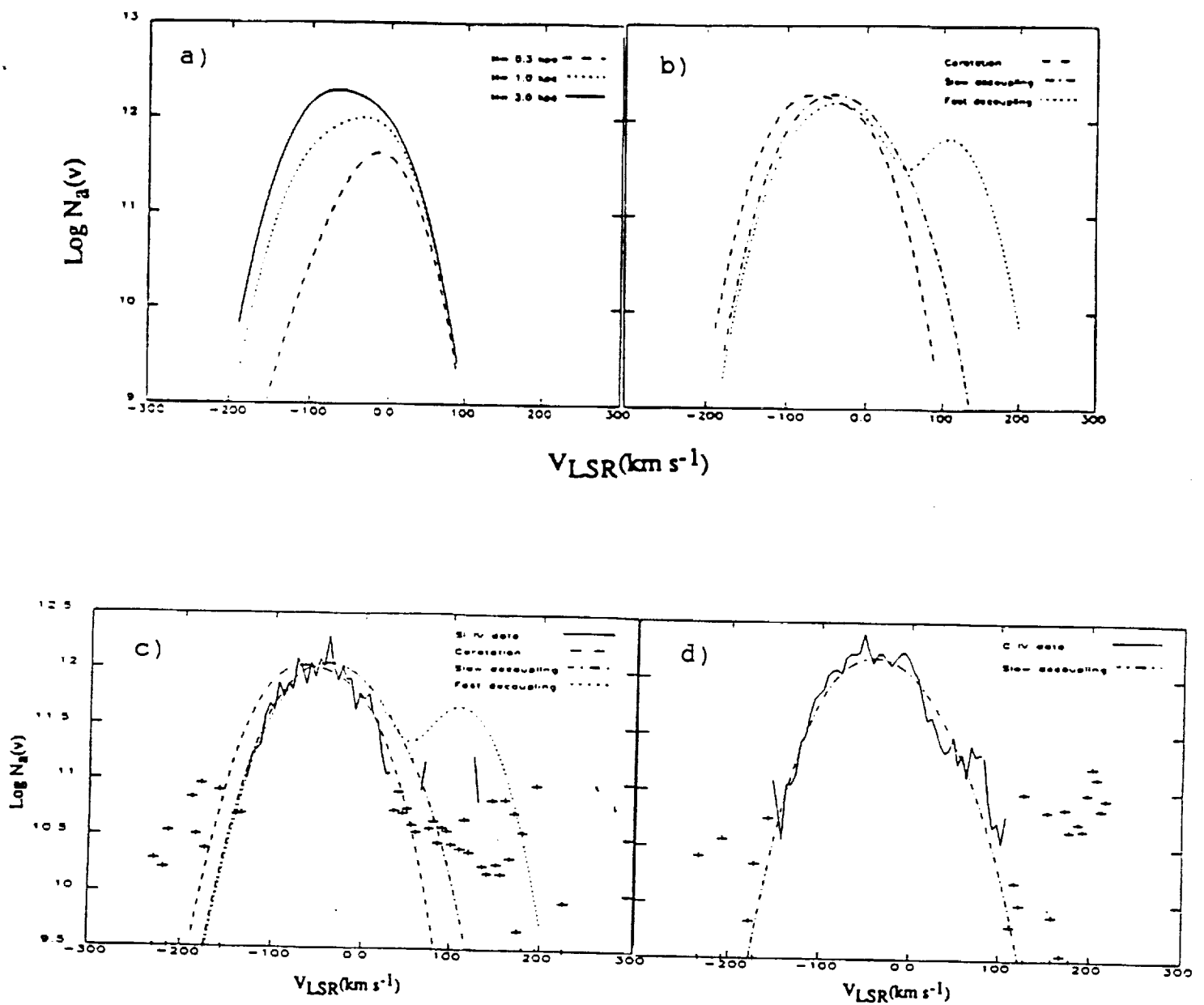


Figure 2 (From Sembach, Savage and Massa 1991). Figures 2a and b illustrate how changing parameters in the halo model affect the calculated profile for the line of sight toward HD 156359. Fig. 2a shows the effect of changing the scale height of the gas from 0.3, to 1.0 to 3.0 kpc (altering the mid-plane density amounts to a simple vertical translation). Fig. 2b shows the effect of changing the velocity law in the halo from corotation, to a situation where the gas begins to decouple from the rotation in the plane at  $|z| = 1.5$  kpc and comes completely to rest at  $|z| = 3.5$  kpc (slow decoupling) to a model where the gas begins to decouple at  $|z| = 1$  kpc and comes to rest at  $|z| = 1.5$  kpc (fast decoupling). Figures 2c and d compare the observed Si IV and C IV profiles to the models. The lack of absorption at large negative velocities in both profiles suggests that some sort of a break-down of corotation is occurring in the halo.

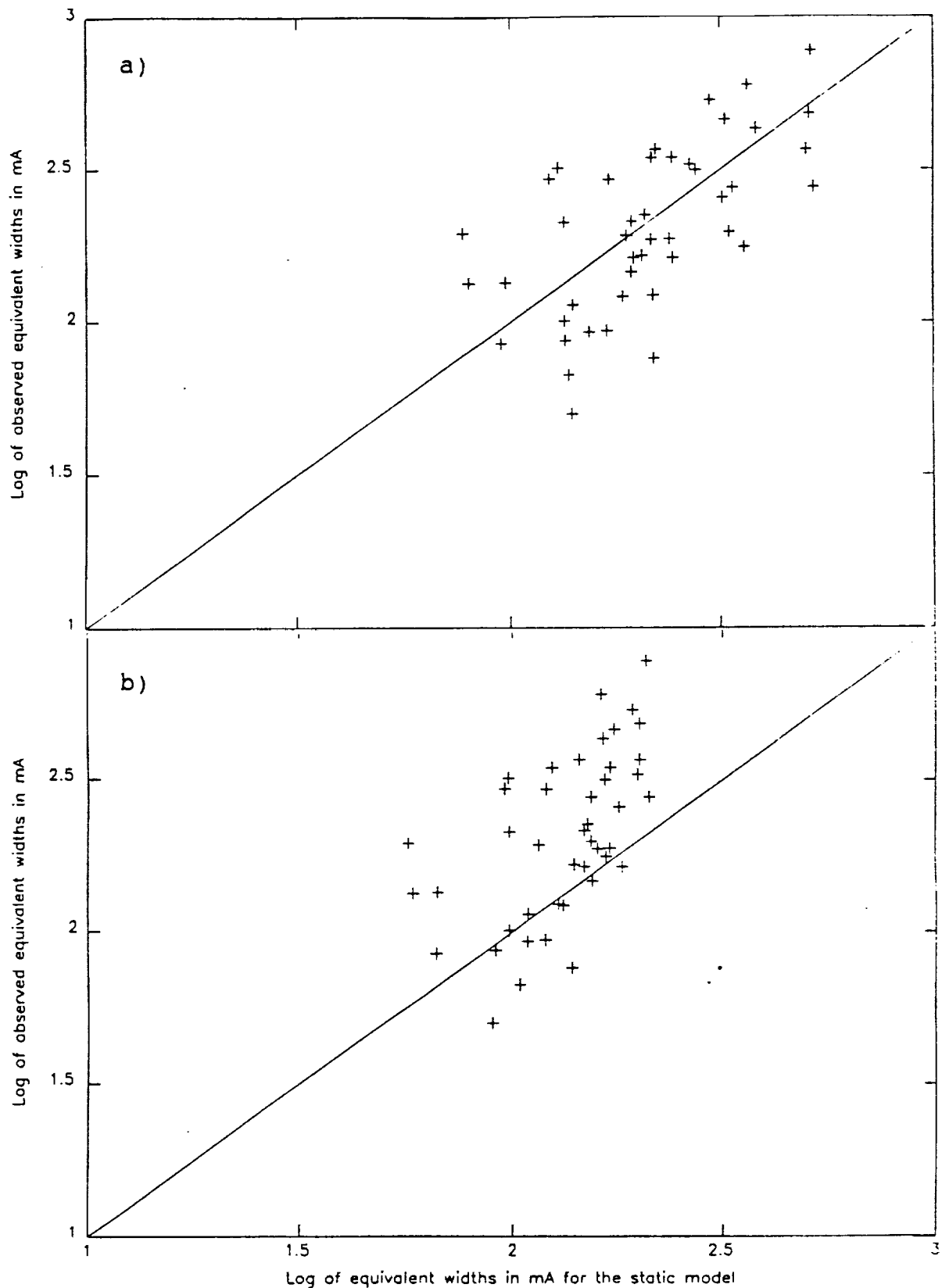


Figure 3. Log of the observed C IV equivalent widths in mÅ versus those derived from models. The line in each figure has a slope = 1 (all the points would lie on the line if the model were perfect). Figure 3a is the best fit for a model which includes Galactic rotation, assumes corotation in the halo, and has been optimized to determine the mid-plane density and scale height of the gas. Figure 3b shows the same data plotted against a model which ignores Galactic rotation.

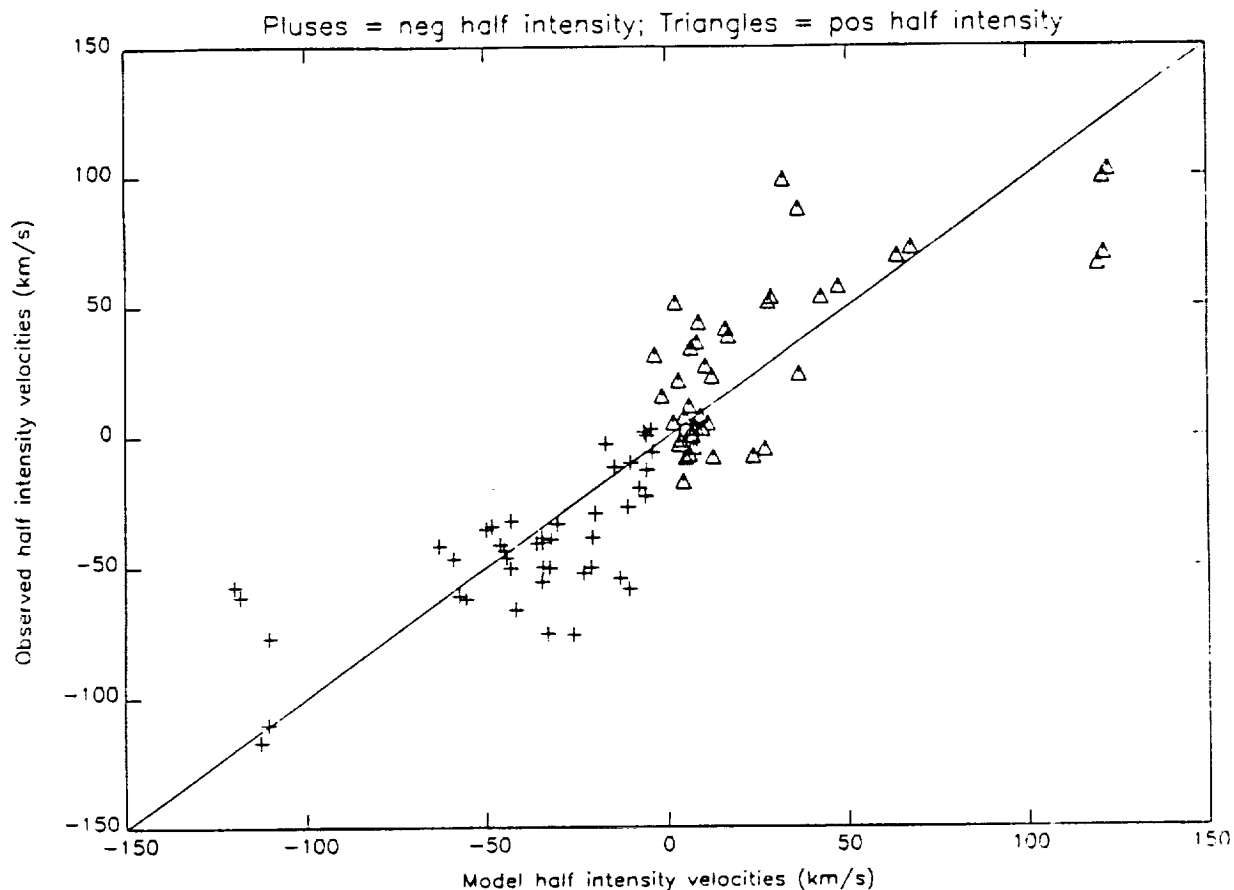


Figure 4. The observed C IV half intensity velocities versus those derived from a best fit model which includes Galactic rotation, assumes corotation in the halo, and has been optimized to determine the mid-plane density and scale height of the absorbing gas. The crosses and triangles represent the negative and positive half power points, respectively, and the line shown has slope = 1. Notice that the deviations about the line have a distinct "S-shaped" pattern which is unaccounted for by the simple model.



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